True as Touch?

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Chapter 7

Summary and Discussion

Most people perform haptic search tasks so now and then, for example when you try to find a pen in your bag to write down a phone number while you are talking to someone. Finding a pen in your bag seems to be a lot more complicated than you would think. The experiments described in this thesis were all designed to get clearer knowledge about the way we perceive and recognize objects with our fingers. The way tactile information from the finger pads and proprioception about the position of the arms, hands and fingers is processed and combined were investigated using mainly the haptic search paradigm.

Overview of Chapters

To investigate how the touch sense handles information collected by the different fingertips, several experiments were conducted. In chapter 2, a model is proposed that describes parallel and serial processing across the fingers. To test this model, participants performed three haptic search experiments, in which a target and distractors were presented to the fingertips of healthy participants. They indicated either a target's presence by lifting the corresponding finger, or its absence by lifting all fingers. In one experiment the target was a cross and the distractors were circles. In another the target was a vertical line and the distractors were horizontal lines. In both cases we found a serial search pattern. In a final experiment the target was a horizontal line and the distractors were surfaces without any contours. In this case we found a parallel search pattern. We conclude that the model can describe our data very well.

In a haptic search task as described above, separate items are presented to individual fingertips. The time to find a specific item generally increases with the number of items, and thus with the number of fingers. Is it the number of items or the number of fingers that determines search time? In chapter 3, we conducted a second study in which tactile horizontal line stimuli were presented to either two, four or six of the participants' fingertips. The task for the participant was to lift the finger under which they did not feel (part of) a line. In one of the conditions separate non-aligned lines were presented to the fingertips, so that the number of items increased with the number of fingers used. In two other conditions the participants had to find an interruption in a single straight line under one of the fingertips. These conditions differed in the size of the gap. If only the number of items in the tactile display were important, search times would increase with the number of fingers in the first condition, but not depend on the number of fingers used in the other two conditions. In all conditions we found that the search time increased with the number of fingers used. However, this increase was smaller in the single line condition in which the gap was large enough for one finger to not make any contact with the line. Thus, the number of fingers involved determines the haptic search time, but search is more efficient when the stimulus can be interpreted as consisting of fewer items.

In chapter 4 the influence of movement on the perception of small tactile stimuli was studied. Two haptic serial search tasks were used to investigate how the separations between items, and the number of fingers used to scan them, influence the search time and search strategy. In both tasks participants had to search for a target (cross) between a fixed number of non-targets (circles). The items were placed in a straight line. The target's position was varied within blocks, and inter-item separation was varied between blocks. In the first experiment participants used their index finger to scan the display. As expected, search time depended on target position as well as on item separation. For larger separations participants' movements were jerky, resembling 'saccades' and 'fixations', while for the shortest separation the movements were smooth. When only considering time in contact with an item, search times were the same for all separation conditions. Furthermore, participants never continued their movement after they encountered the target. These results suggest that participants did not use the time in between the items to process any information about them. When comparing these results to the results of the first study, where the participants were shown multiple items to their fingertips simultaneously, the search times were a little faster in this study. To investigate whether this effect is caused by the movement of the finger or by the use of just one finger instead of multiple fingers, we asked participants to put three fingers in line and use them together to scan the items in a second experiment. Compared to the first experiment, time in contact with the items increased for all separations, so it was the use of one finger that caused the faster search times in the first experiment compared to the static search experiment. This may have been caused by the time that it takes to switch from one finger to the other.

In chapter 5 larger stimuli were used. To investigate how well people are able to combine tactile and proprioceptive information, we conducted a haptic search task in which participants had to search for either a cylinder, a bar or a rotated cube amongst cubes with one finger. To detect a cylinder only tactile information is needed. For detecting an oriented cube touch alone is not enough. The shape is identical, so it is only detectable in combination with static proprioception (orientation of the finger in space). For the bar one must mainly rely on a combination of touch and dynamic proprioception (distance and direction of one's movements). The bar was most difficult to find with search times that were much higher than for the other two conditions. The oriented cube had similar search times to the cylinder but it produced most errors. This suggests that combining proprioception with tactile information does not take additional time but it does result in additional errors. In a second experiment participants were allowed to used their whole hand. The exploration time per item was much lower for bar and oriented cube and for cylinder it was the same as in the one finger condition, moreover the search times for the different shape conditions were the same in the whole hand condition. The proportion of errors was lower in the whole hand condition than in the one finger condition. These results indicate that when using objects that can be enclosed by the hand, proprioception is not an important factor when using the whole hand. We also included a condition in which the participant could use two hands. By doing so, the search times halved compared to. This indicates that two hands can process information in parallel.

The last chapter (chapter 6) describes a study in which the influence of finger configuration on the ability to localize a tactile stimulus was studied. Participants had to localize tactile stimuli applied to their fingertips. We measured the number and locations of errors that participants made in three configurations: fingers together, fingers spread and fingers interwoven. We reasoned that if there are tactile receptive fields that span more than one finger, fewer errors will be made when the fingers are spread. We indeed found that fewer errors were made when the fingers were spread. However, the reduction of errors was not specific to the neighbouring fingers. This suggests that more distinct information about the positions of the fingers can improve tactile detection.

Visual Search

The experiments in chapter 2 are most comparable to the traditional visual search paradigms used by for example Treisman and Gelade (1980). In this paradigm a target has to be found between varying numbers of distractors, which are shown in the visual field. It is generally found that the search time increases with the number of distractors (serial search), unless the target has a characteristic feature that the distractors do not have (parallel search). The serial search functions we found in the static search experiments of chapter 2 are similar to serial search function found by Treisman and Gelade. However, the parallel search pattern (also found in chapter 2) is different than the one that is normally found in visual search. In visual search a search is considered to be parallel when both the functions for target present and absent have a zero slope (e.g. Brown et al., 1992b; Treisman & Gelade, 1980). In visual search the number of items in the display is varied, but in static haptic search also the number of fingers is varied. This might be the cause of the difference between visual and haptic search patterns. To further investigate this we designed an experiment that is described in chapter 3. We investigated whether the number of fingers or the number of items is more important in determining the search time. We found that it is mainly the number of fingers that determines that the search is serial. So the difference between the patterns in haptic and visual search can be explained by the use of multiple sensors in haptics compared to just one visual field (or two retinas) in vision.

The other haptic search experiments (chapter 4 and 5) are more comparable to visual search experiments in which eye movements have to be made. In chapter 4 is investigated what influence spacing between items has on haptic search strategies. It was found that the finger has to stay in contact with an item in order to process it. After processing of an item is finished one can leave the item and move on to the next one (chapter 4). In visual search is found that participants continue to the next item, and then return to the item they just saw, even if they have to make hand movements to move their field of view (Hooge & Erkelens, 1996; Liesker, Smeets, & Brenner, 2007).

Touch and Haptics

Parallel and serial search times are apparently determined by the use of multiple fingers (chapter 2 and 3). Either one has to switch from one finger to another, or has to wait till all fingers have finished processing (chapter 2). Also in chapter 4 and 5 we find that fingers can either work together (parallel processing) or are interfering with each other (serial processing, with time costs for switching from one finger to the other). When in touch with objects that are bigger than the size of one's fingertip it is relatively easy to combine the information that is gathered at the different fingertips. However, when in touch with small objects it is much more difficult to combine this information, which results in serial processing with time costs for switching between the different fingers. When an object is bigger than the fingertip, proprioception can help in the recognition of this object (chapter 3 and 5).

These conclusions are in agreement with the studies on the anatomy of somatosensory cortex I and II (SI and SII) mentioned in the introduction. In SI there are areas in which each finger has its own representation (Kurth et al., 2000), so low level discrimination between two items could happen in SI. Whether these items are processed serially or in parallel, depends on the characteristics of the stimuli (Lederman & Klatzky, 1997). When the items that are touched are larger than a fingertip, more fingers are needed to recognize the object. Recognition where proprioception is needed take apparently place in SII, because in SII there are areas in which the posture of the hands can modulate the representations of the fingers and there are overlapping receptive fields over fingers present (Hamada & Suzuki, 2005; Simoes et al., 2001). We found in chapter 6 that these overlapping receptive fields are not used when localizing simple tactile stimulation at the fingertips, so apparently these localizations are already made in SI.

Searching for a Pen

To return to the search for your pen: according to chapter 2 it is difficult to process spatial features in parallel, except when just one of your fingers feels a stimulus. Touching more than one object with one hand can in that sense make the search process a lot more complex. On the other hand, when you touch one pen with multiple fingers, it speeds up recognition time considerably (chapter 3). When there is enough space in your bag to move your finger over the pen, it helps to get information about the shape of the object (chapter 5), however it does not necessarily speed up the processing of the spatial characteristics of an object (chapter 4). When using the whole hand to enclose the pen you do not even have to take proprioception into account and you can feel the shape immediately (chapter 5). If you want to be twice as fast as using your whole hand, you have to use two hands (chapter 5).

Final Remarks

We now know a bit more about the way people scan their environment in the haptic modality and how information collected by the fingertips is processed into a single or multiple percepts. However, there are many more interesting factors one could look at. For example, in this thesis I only looked at different spatial characteristics of objects, but did not take other object dimensions into account, such as material properties. It may be much easier to find a pen made out of metal than a pen made of plastic between for example wooden pens. Processing other kinds of tactile information might be very different than processing spatial information.

Holding multiple objects in one hand can also be investigated. How do you feel that you are holding multiple objects in stead of one object and how can the different information sources from your hand be combined to get multiple percepts? How do you recognize the different objects you are holding?

Furthermore, in daily life you rarely encounter that you need to search for something in the complete lack of visual information. When searching for a pen in your bag visual information is still present, although it is not relevant. Can this non-relevant information help you in knowing where your hand is?